EXPERIMENTAL FRICTIONAL HEATING OF DOLOMITIC MARBLE: NEW INSIGHTS FOR MARTIAN METEORITE ALLAN HILLS 84001.

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Summary: One of the major questions concerning the history of Allan Hills 84001 is the origin and modification of the carbonates. Scott *et al.* [1] have proposed that some carbonates were melted and redistributed by shock during an impact event. However, recent shock experiments suggest that carbonates do not melt, even when subjected to shocks greater than 50 GPa [2]. Scott and Krot [3] responded that shock heating of minerals is likely controlled by shear stresses rather than shock alone, or that shock pressures in ALH84001 exceeded 50-60 GPa in order to produce carbonate melts. There is little to no evidence in ALH84001 for shock pressures exceeding 35-40 GPa, while there is abundant evidence for shear deformation [4]. The characteristics of ALH84001 crush zones are remarkably similar to those in a terrestrial ultramafic pseudotachylite [4]. These observations suggest that some minerals, such as plagioclase and carbonate, within the crush zones may have undergone frictional heating and melting during deformation, a process which has been described by Spray (1995) [5]. Our present experiment, frictional heating of dolomitic marble, suggests that carbonates may be melted during high strain-rate deformation. As a result, it may be possible that melting of carbonates in ALH84001 occurred during high strain-rate deformation during an impact without shock pressures exceeding ~40 GPa.

Background: Initial observations of ALH84001 by Mittlefehldt (1994) [6] described the presence of two populations of carbonates, pre-shock and post-shock. Small carbonates present in the crush zones, were either formed after the main shock event, or were remobilized by that event [6]. Since then, more detailed descriptions of the carbonates have produced more morphological groups [e.g., 7]: (a) globules, (b) interstitial grains within recrystallized areas, (c) large veins (edge-on globules), (d) fracture and pocket fillings within cumulus pyroxene, and (e) lacy carbonate coexisting with plagioclase glass [7]. Small carbonates within crush zones and some fractures are still suggested to result from shock [1]. In addition, McKay *et al.* [7,8] propose that lacy carbonate along with adjacent plagioclase glass form simultaneously during crystallization of a shock melt.

However, evidence for high shock levels in ALH84001 is absent, whereas evidence for shear deformation is pervasive [4]. The presence of "augen" or "ribbon" shaped orthopyroxene, chromite stringers, elongated bands of Fe sulfides, "boudinage-like" olivine grains, cataclastic shear zones, and plagioclase, carbonate and silica melts are all indicative of high strain-rate deformation and melting [4]. Scott *et al.* [9] describe a plagioclase-carbonate grain that has trails of small carbonate and plagioclase glass grains associated with it. Small carbonate grains are distributed along the crush zones and cracks within pyroxene [1]. Plagioclase grains are frequently affected by cataclasis or granulation [10]. Carbonate globules are disrupted and dispersed within plagioclase composition glass [7]. These relationships are consistent with shear deformation. In addition, Scott and Krot [11] and Foley *et al.* [12] describe morphologies of plagioclase glass and Fe sulfide grains as similar to those found in "shock-melted" L chondrites. As shown in previous experiments, some of these morphologies in fact are the result of high strain-rate deformation, rather than high shock pressures [13].

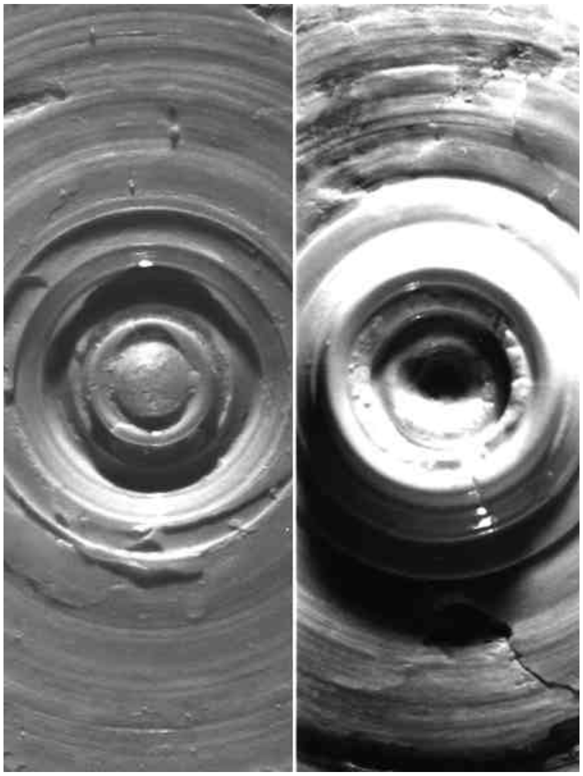

Figure 1. Close up view of experimentally friction heated contact surfaces. Dolomitic marble on the left; quartzite with adhered carbonate on the right. Height of photo is ~1 cm.

Recent shock experiments on Homestake Formation carbonates result in decomposition of carbonate at high shock pressures (up to 51.2 GPa) without generating carbonate melts [2]. Even at a shock pressure of 85 GPa, only partial shock melting occurs with more pronounced degassing of the

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carbonate [14]. These results, especially in the absence of high shock indicators in ALH84001, suggest that the carbonates may have melted by a mechanism other than shock.

Experiment: One 2 cm^3 sample each of dolomitic marble and quartzite were mounted onto steel cylinders. Using a Blacks FWH-3 axial friction welding rig, the samples were brought into contact at room temperature, atmospheric pressure, and under dry conditions as described in Spray (1995) [5]. Contact was maintained for 2 seconds at 750 rpm. The dolomitic marble was welded against quartzite to prevent failure of the dolomitic marble should it degas during the experiment.

Results: During frictional heating the carbonate sample glowed red, indicating that the temperature achieved during the experiment was at least 900° C to 1000° C. Carbonate material adhered to the quartzite sample forming a small cone of harder material, which worked a mirror image geometry into the surface of the carbonate sample (Figure 1). The surfaces of each work face are shiny, exhibit small radial cracks, and thin plates of elevated material. The composition of this material is presently being determined.

Preliminary observations of the thin section (Figure 2) reveal that the carbonate material which has adhered to the quartzite sample is composed of many submicron fragments of dolomitic marble that are likely welded together with glass. The welded material contains foliations defined by varying shades of brown, perhaps controlled by glass content or composition. Some of the carbonate material is injected into small cracks in the quartzite.

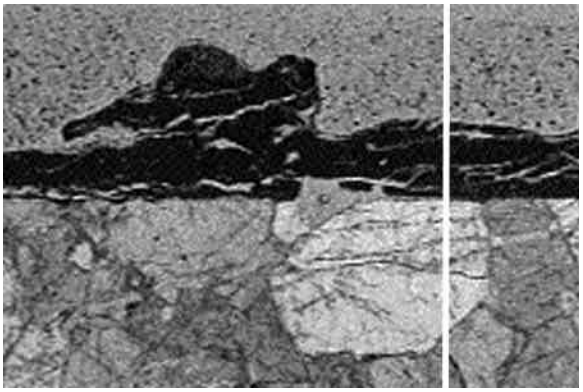

Figure 2. Plane-polarized view of quartzite sample (bottom half) with adhered carbonate material (dark/ opaque). White line is the vertical axis of rotation. Width of view is ~1 mm.

Implications for Allan Hills 84001: The failure of shock experiments to produce carbonate melts coupled with the generation of possible melts via frictional heating, suggest that high strain-rate deformation and melting may have occurred in ALH84001. This melting may be responsible for the small carbonate grains within the crush zones and some of the thin carbonate veins. High strain-rate deformation probably generated the plagioclase melts associated with these carbonates. High shock levels are not required to generate the carbonate melts; they may be produced during high strain-rate deformation alone. This conclusion is supported by the absence of shock features indicative of high shock in ALH84001, and is consistent with the observations of Mittlefehldt (1997) [15], who finds no textural evidence for a major post-carbonate deposition shock event and the conclusions of [4] who document abundant evidence for shear deformation in the meteorite. Carbonate melts in this scenario would be generated from preexisting carbonates [e.g., 16, 17]. If the carbonate materials were emplaced as submicron melt-breccias, recrystallization to larger grains is required and not improbable.

Implications for carbonate targets: High strain-rate processes with or without high shock levels may be responsible for the formation of carbonate impact melts in terrestrial craters, especially since high shock levels are not known to produce carbonate melts. Friction melting is an effective means of melting large volumes of carbonates during the high strain-rate deformation that accompanies impact events. High strain-rate deformation may produce carbonate breccias and melts associated with craters such as Sierra Madera [18].

Conclusions: Observations of impact materials, coupled with numerous recent experiments suggest that high strain-rate deformation is an important component of the impact process. Some features ascribed to shock deformation are in fact the result of high strain-rate deformation (e.g., some types of “shock” veins [13]). The role of high strain-rate deformation certainly does not replace the unique importance of shock deformation during impact, but these new insights require a renewed investigation of the clues that these processes leave behind.

These new experiments and observations suggest that high strain-rate deformation rather than high shock levels may be responsible for some of the enigmatic petrology of ALH84001.

References: **[1]** Scott *et al.* (1997) *Nature* **387**, 377-379. **[2]** Schwandt *et al.* (1998) *Meteoritics* **33**, A139. **[3]** Scott and Krot (1998) *LPI Contribution 956*, 44-45. **[4]** van der Bogert and Schultz (1998) *LPI Contribution 956*, 56-58. **[5]** Spray (1995) *Geology* **23**, 1119-1122. **[6]** Mittlefehldt (1994) *Meteoritics* **29**, 214-221. **[7]** McKay *et al.* (1997) *Ant. Met.* **23**, 106-108. **[8]** McKay *et al.* (1997) *Meteoritics* **32**, A87-A88. **[9]** Scott and Krot (1998) *LPSC* **29**, #1786. **[10]** McKay *et al.* (1998) *Ant. Met.* **23**, 75-76. **[11]** Scott and Krot (1997) *LPSC* **28**, 1271-1272. **[12]** Foley *et al.* (1998) *LPSC* **29**, #1928. **[13]** van der Bogert *et al.* (1998) *LPSC* **29**, #1693. **[14]** Langenhorst *et al.* (1998) *Meteoritics* **33**, A90. **[15]** Mittlefehldt (1997) *Meteoritics* **32**, A93. **[16]** Shearer and Adcock (1998) *LPSC* **29**, #1280. **[17]** Scott and Krot (1998) *Meteoritics* **33**, A139-A140. **[18]** Wilshire *et al.* (1972) *Geol. Surv. Prof. Paper 599-H*, 42 p.